MODIS DATA STUDY
TEAM PRESENTATION

August 25, 1989

AGENDA

1. Considerations Regarding the Direct Broadcast of Real-Time MODIS Data.
2. Algorithm for Estimating Aerosol Optical Depth Over Dark Green Vegetation.
3. Trade Offs Involving the Processing of the Small and Large Volumes of MODIS Data.
4. Straw-Man Beginning to the MODIS Core Data Product Processing Scenario.

Considerations Regarding the Direct Broadcast of Real-Time MODIS Data

In its role as an intermediary between the MODIS Science Team and the data system design community, the MODIS Data Team must receive basic science data requirements from the Science Team and interpret these requirements to data system designers, who are, in turn, charged with responsibility to implement the data systems needed to support the science effort. Recently in the Eos project, the possibility of direct data broadcast from the Eos platform to ground receiving terminals is receiving serious attention, and this document is a first attempt to lay out the questions that the Science Team must answer to define science requirements for this system feature.

Since direct data broadcast is a new capability not yet seriously considered by the MODIS Science Team, the initial questions to be asked relate to the scientific utility of the new system options that this feature could potentially support. At this very earliest stage, it is desirable to mimimize the technical and cost constraints associated with the new capability and to emphasize instead the wide range of new possibilities that this feature opens up. Accordingly, where clear and overriding technical or cost constraints have been defined, they are included in the discussion below. However, most issues are "wide open", and Team Member proposals and comment are solicited.

Technical Features of the Direct Broadcast Capability

What radio frequency band would best serve the needs of the user community?

Since Landsat 4 and 5 use the X-band and a network of ground terminals already exists to serve Landsat needs, it is often thought that the X-band may be the optimum choice. The S-band is also frequently suggested as a possibility.

Ground terminal capabilities also presently exist to support APT and HRPT data receipt from NOAA polar orbiters. Furthermore, low cost ground stations running on an IBM PC and MacIntosh SE are capable of picking up direct broadcast real-time data from the NOAA polar orbiters, GOES, Meteor, Meteosat, and other polar and geostationary spacecraft.

What is the required data throughput capability of the direct broadcast link?

Should data be broadcast whenever the satellite is within range of a ground terminal or only upon request? If only on request, how would multiple requests be adjudicated?

What sort of ground terminal support might be needed to request and receive direct broadcast data?

Should the direct broadcast system support only the real-time transmission of data as observations are made, or should data for direct broadcast be retrievable from the on-board tape recorder?

Would direct broadcast service need a high-gain antenna at the satellite that must be aimed at the user's ground terminal? If the antenna must be aimed, how widely separated can users be and still receive simultaneous service?

Nature of Direct Broadcast Data

What type or types of data should be transmitted? Would the direct broadcast service transmit only one type of data or could the user select among several types of available data?

One suggestion is that composite products useful for data browse might be produced. Another suggestion is that key parameters that determine the usefulness of data, e.g. cloud cover, might be produced for direct broadcast.

What processing should the data receive before broadcast?

The MODIS processing to be considered is limited to that achievable within the physical confines of the MODIS instruments. Platform computing facilities are not expected to be available for MODIS data processing.

Use of Direct Broadcast Data

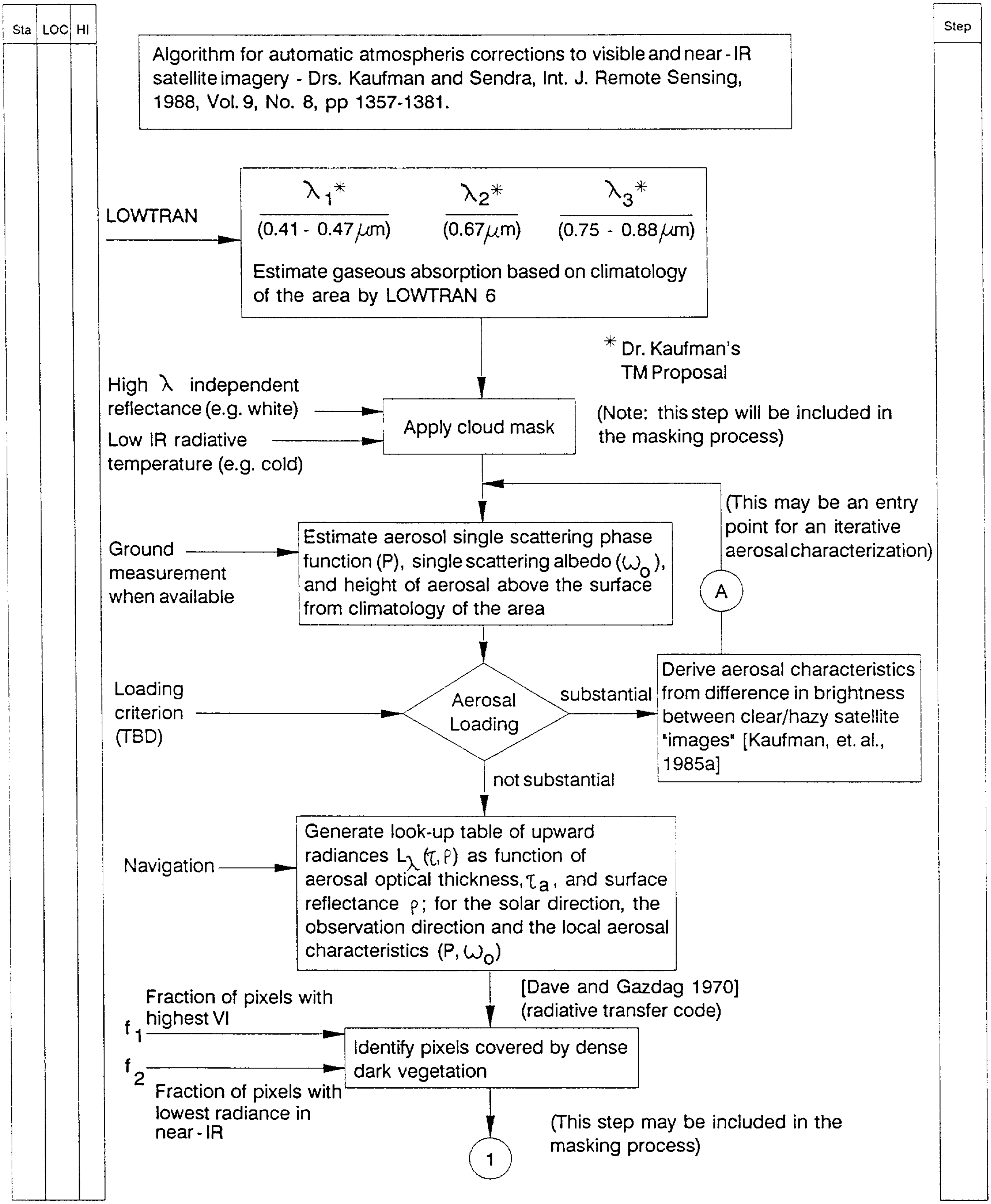
Who would have access to direct broadcast data after receipt at the ground terminal? Science Team Member only? General public? How would data be distributed?

Will data products based on direct broadcast data be distributed through EosDIS?

Would direct broadcast data be used to support instrument monitoring? Is direct broadcast acceptable or useful as a backup link for real-time instrument monitoring data routinely routed through the TDRSS?

Impact of Direct Broadcast Capability

What adjustments must be made in standard MODIS data processing to accommodate direct broadcast capability?



Algorithm Status	LOC	Current Human Intervention
O - Operational	Lines	A - Autonomous
D - Development	of	H - Some Human
C - Conceptual	Code	M - All Manual

Sta	LOC	HI

1

Compute aerosal optical thickness (τ_a) for each pixel identified

(Pixel radiance (L_m) & reflectance (ρ) for $\boxed{\text{each } \lambda}$ $\rightarrow$ Table (L_λ) $\rightarrow \tau_a$ by interpolation)

Generate map of $\tau_a(\lambda, x, y)$ by interpolating and smoothing the measured values.

(i) For each pixel for which τ_a is interpolated, construct a box with $2\eta+1$ pixels on a side such that the subject pixel is in the box center. Start with $\eta=1$.

(ii) Compute $\bar{\tau}_a$ from pixels within the box.

(iii) If there were < 3 values of τ_a within the box increment η 2 +1 and go to step (i).

(iv) Perform steps (i) - (iii) for all pixels for all λ's for which τ_a is available.

(v) For each pixel, compute slope ν where,

$$\nu = -\ln\left(\frac{\tau_{a1}}{\tau_{a2}}\right) / \ln\left(\frac{\lambda_1}{\lambda_2}\right).$$

The average value of ν on the entire subarea (ν') is used interpolate and extrapolate the values of τ_a for other bands (e.g. τ_{a3} for λ_3).

Climatology $\tau_a(\lambda_i) \rightarrow$

$$\tau_{a3} = \tau_{a1} \exp\left[-\nu \cdot \ln\left(\frac{\lambda_1}{\lambda_3}\right)\right].$$

The averaging of ν decreases the noise introduced in its computation.

ν may be used to test/change value of assumed phase function, P by an algorithm, TBD

A

2

Step

Sta	LOC	Hi

2

Perform atmospheric correction.

Theoretical tables →

Surface uniformity (from mask) →

Switch criterion →

Uniform surface:

Interpolate L_o, F_D, s from theoretical look-up table;

then,

$$\rho = f/(1+sf)$$

where,

$$f = (L - L_o)/(TF_D)$$

Non-uniform surface:

Divide image into 2 - 10 km sectors.
Correction applied per sector for $\bar{\tau}_a$;
look-up L_o' & $M(k_x, k_y)$, then,

$$\rho(x, y) = \mathcal{F}^{-1}\left\{\mathcal{F}\left[L(x, y) - L_o'\right] / M(k_x, k_y)\right\} F_o \mu_o$$

Step

Should MODIS data be processed in scan cubes or scene cubes?

The term "cube" is a misnomer conceptually denoting the three (unequal) dimensions of number of observations taken along-track, number of observations taken across-track, and number of spectral bands.

A "scan cube" (or swath cube) is the amount of data swept out by the MODIS-N or MODIS-T instrument during the course of a single cross-track scan. It can include off-earth calibration and other ancillary data (assumed to be 10% of the earth data).

A "scene cube" (or image cube) is a collection or concatenation of scan cubes to obtain a data set with approximately equal dimensions in the along-track and across-track dimensions. The term "equal" may refer to the areal coverage or to the number of scan lines and observations within the scan line. Here we will use the former definition.

Person A argues: **MODIS data should be processed in scan cubes for the following reasons:**

1. "A scan cube is one of the smallest elements of MODIS data that makes physical sense."

2. "A Level-1B scan cube will contain on the order of .45 to 1.7 megabytes of MODIS-N data (night or day), and 2.5 megabytes of MODIS-T data. This could fit into a contemporary mainframe without too much trouble (triple it to account for Level-2 product storage, other arrays and look-up tables, and the code)."

Person B argues: **MODIS data should be processed in scene cubes for the following reasons:**

1. "The roughly 100,000 scan cubes to be generated by MODIS-N and -T daily would require too much DBMS effort to keep track of."

2. "It should be possible to store 300+ megabytes of data in random access memory in the supercomputer EosDIS will procure for the CDHF."

3. "Processing the MODIS data in little chunks will cause too much trouble at the along-track scan boundaries."

[Arguments are to represent possible points of view and not definitive information.]

MODIS CORE DATA PRODUCT PROCESSING SCENARIO - FOR DISCUSSION ONLY

This is a first cut at a processing scenario for the MODIS core data products, due at the end of October, 1989. The purpose of this scenario is to show the data flows, the priorities in the processing, and the dependencies of the core data products upon one another. This version of the processing scenario presents a candidate scheme for controlling the processing and managing the data (See Figure 1).

1. MODIS DATA EVOLUTION FROM INSTRUMENT THROUGH LEVEL-0 PROCESSING

1.1 Relevant Instrument Characteristics of MODIS-N and MODIS-T

The center wavelengths and instantaneous fields of view (IFOVs) for the MODIS-N and MODIS-T bands are presented in Table 1. MODIS-T is equipped with 32 spectral channels, and MODIS-N with 36. Of course, the precise design of the two MODIS instruments may still be subject to change in the near future.

The MODIS-T instrument is assumed here to be configured with a 32 X 32 detector element array. We assume that 32 detectors are oriented along the satellite's track, and the other dimension of 32 is in spectrum (yielding 32 bands). The MODIS-T bands all possess 1 km IFOVs at nadir, and have band passes designed to measure reflected solar radiation in the wavelength shortwave and near-infrared spectral regions.

The MODIS-N instrument is assumed here to be configured with a total of 480 detectors (Table 2). Conceptually, these detectors are partitioned into three arrays: one for the 428 m bands and two for the 856 m bands[1]. The 856 m detector arrays are defined for the reflected and emitted bands and are 8 detectors deep along the ground track, and 12 or 16 detectors deep in the spectral dimension, respectively (8 X 12 and 8 X 16). We assume that the 428 m bands are 32 X 8, or approximately 8 km along track by 8 spectral bands. For the remainder of this document, we will use the terms "1 km" and "856 m" to identify the MODIS-N 856 m bands, and the terms "428 m" and "500 m" to identify the MODIS-N 428 m bands.

The data rates and volumes for the MODIS-N and MODIS-T instruments are presented in Table 2. We assume a universal 12-bit A/D conversion, and that the MODIS-N and MODIS-T reflected bands operate on a 50% duty cycle (taking all available data when the solar zenith angle is less than 180°). We also assume that the MODIS-N and MODIS-T instruments scan out to ±55° and ±45°, respectively, and maintain contiguous spatial coverage between adjacent IFOVs. The MODIS-N instrument is expected to have a scan period of 1.02 seconds, taking either 9.1 or 2.4 megabits of

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[1]The MODIS 856 m channels derive from an operational requirement that the MODIS-N instrument have a 1 km IFOV at an orbital altitude of 824 km. At the expected Eos-A platform altitude of 705 km, the effective IFOV at nadir is 856 m.

science data during each scan (for daytime and nighttime, respectively). The MODIS-T instrument is expected to have a scan period of 4.75 seconds, taking 13.6 megabits of science data per scan (daytime only). Assuming a 10% contingency for housekeeping and other MODIS ancillary data, the effective data volumes are 10.0 or 2.6 megabits per scan for MODIS-N, and 15.0 megabits per scan for MODIS-T. The corresponding peak data rates are 9.9 and 3.2 megabits per second, respectively, for the MODIS-N and MODIS-T instruments (averaged over the scan).

1.2 Level-0 Data Characteristics

We assume that the Level-0 data, made available to the CDHF for MODIS standard product generation by the DHC, will consist of a number of different types of data packets. The two basic types of packets will be MODIS data packets and platform ancillary data packets.

The platform ancillary data will include ephemeris and attitude data describing the position and orientation of the platform, and time-dependent distortions of the platform between the "nav base" (where the data will apply) and the MODIS base plate if available. A summary of the operating status of all of the platform instruments (and perhaps of instruments on other platforms as well) will also be useful. An update frequency for the platform ancillary data of every 0.1 to 1.0 seconds should be adequate, but will depend on the rate of change of the platform attitude.

A number of types of MODIS data packets have been previously been identified as desireable. These include a specialized engineering packet for the real-time/near-real-time monitoring of the health of the MODIS instrument at the ICC (not to be discussed further here), a MODIS ancillary data packet, and a unique data packet for each spectral band of MODIS-N and MODIS-T (though not for each detector). A total of 71 different types of data packets will be required at the CDHF for MODIS standard product generation: the platform ancillary data packets, the MODIS ancillary data packets (one each for MODIS-N and MODIS-T), 32 MODIS-T data packets, and 36 MODIS-N data packets. All data packets will be time tagged at generation, and (we assume here) will have been Level-0 processed (bit reversed, error corrected, time ordered, duplicates removed, and gaps filled) by the DHC prior to delivery.

The MODIS ancillary data packets will contain all engineering and housekeeping data required to navigate, calibrate, and interpret the MODIS sensor data. For example, the ancillary data will include words and bits describing the operating status of the instrument, the output of the temperature monitors, the encoded positions of the scan mirrors, and power supply and electronics diagnostics. Due to the importance and relative low rate for this packet type, a duplicate packet should be sent to guarantee delivery.

Each of the 32 bands from the MODIS-T instrument will take 32 observations along-track and approximately 1,107 observations across-track during each scan (35,424 observations). Each of the 28 MODIS-N

1 km bands will take 8 observations along-track and approximately 1,582 observations across track during each scan (12,656). Each of the eight MODIS-N 500 m bands will take a total of 50,624 observations during each scan (four times the data of a 1 km band). Specific information regarding the design of the MODIS-N and MODIS-T instruments is not available at this time. We will assume that 8% of the 10% data contingency factor is due to off-Earth calibration-related observations (e.g., space-look, moon-look, solar calibration, black-body calibration). There are then 38,258, 13,668, and 54,674 measurements per band in each scan for the MODIS-T, MODIS-N 1 km, and MODIS-N 500 m channels, respectively. At a 12-bit quantitization, 459, 164, and 656 kilobits of data are required to obtain a complete scan for each spectral band. Of course, during nighttime, only the 16 MODIS-N thermal bands will generate data packets, except for specially requested calibation-related observations.

As defined in CCSDS Standard 102.0-B-2 [Packet Telemetry], up to 8,240 bits of user-specific data may be included in each data packet. In fact, source data packets may be created with arbitrary lengths and segmented to fit into standard packet lengths. Therefore, it may be both possible and desireable to define each MODIS sensor data packet as one complete scan for a given band, and segment the source packet as required in flight to provide data packets to the platform data system. The Level-0 processing would then reconstruct the original source packet, which would conveniently contain a complete scan of one MODIS band. We will not perform a detailed analysis of segmentation alternatives in this discussion.

There will be 8,240 bits, less an optional secondary header and optional packet error control, available in each data packet for MODIS sensor data. The secondary header can contain the spacecraft time, MODIS sequential scan number, packet sequence within the scan, and any other pertinent information. We will assume that this secondary header is 240 bits long, that the packet error control is not required, and that 8,000 bits (one kilobyte) remain available for the sensor data. Therefore, approximately 57.4, 20.5, and 82.0 packets will be required for the data taken by each band of MODIS-T, by the MODIS-N 1 km channels, and by the MODIS-N 500 m channels. The final packet of the scan could be zero-filled and transmitted to yield a stand-alone scan of data for each band and instrument (or a complete source packet from 21 to 82 source-packet segments).

An additional 48 bits comprise the primary header of the packet, which contains in part an application process ID and a source sequence count. The application process ID will be uniquely specified for each type of MODIS data packet, and will also specify the packet's destination (e.g., CDHF or ICC) and perhaps processing priority (e.g., real time, near-real time, or routine). The source sequence count is 14 bits long, and can contain 16,384 unique values. If each MODIS data packet is a source packet, then there will be approximately 530,000 such packets for MODIS-T for each of the 32 bands (625 scans X 58 packets X 14.6 orbits) per day. This will exceed the range of the source sequence count, requiring that the secondary header be used to uniquely identify each source packet. For MODIS-N, up to 3,500,000 packets per band (5841 scans X 50% duty cycle X 82 packets X 14.6 orbits) would be required per day.

Delivery of Level-0 MODIS data from the DHC to the CDHF would consist of the verified transmission of a group of processed (and possibly reconstructed) MODIS source packets and the corresponding platform ancillary data (possibly no longer in packet form). Depending on the frequency of these deliveries, the group of MODIS data packets might constitute one day (676 gigabits), one orbit, or some other convenient block of data. The total daily MODIS requirement, for all MODIS data packet types, will be for on the order of 85,000,000 data packets (676 gigabits/8 kilobits per packet). At a continuous data rate of 150 megabits per second, approximately 1.25 hours will be required to transfer one day of Level-0 MODIS data from the DHC to the CDHF.

1.3 Non-Standard Processing of MODIS Data

Here we consider briefly several types of processing of MODIS data. These are: (1) Real-time direct-broadcast; (2) Real-time transmissions through TDRSS; (3) priority playback/near-real-time processing; and (4) health and safety monitoring at the ICC and IST.

(1) Real-Time Direct Broadcast

There is strong interest on the part of some MODIS Science Team members for a direct broadcats capability for MODIS data in real time. A primary use of this capability will be in support of field experiments. Here we present one possible scenario for this capability.

The applications process ID, within each data packet's primary header and set by the MODIS instruments, can indicate the destination and processing priority for the data contained in the packet in addition to the type of data the packet contains. A specific setting for the ID could indicate to the platform data system that the data packet should be routed to the direct broadcast system, and copied to the platform tape recorder. Provided that individual packets contain information from a single MODIS band, the user could customize his real-time data request by orbital segment and spectral coverage. Depending on available bandwidth, single to multiple spectral bands could be selected. The orbit for the polar platform is easily predicted 16 (one repeat cycle) or more days in advance, which permits the following scenario: The team member supplies the team leader with a real-time data request, establishing the required bands and temporal coverage (in GMT start and stop times). This information is combined with other team member requests and forwarded to the ICC/EMOC. The corresponding commands are uplinked to the platform and MODIS instrument. During the appropriate intervals, the application process ID of the affected data packets is revised to reflect a real-time/direct-broadcast requirement. The platform data system routes the data packets accordingly.

[others to be inserted]

2. MODIS ROUTINE LEVEL-1 PROCESSING

2.1 General Philosophy

MODIS Level-1 processing begins with Level-0 data as the primary input data source, and concludes with the delivery to long-term archive and higher-level processing of calibrated, Earth-located, MODIS radiances at the top of the atmosphere (TOA) along with relevant ancillary information. EosDIS requirement 1092 [L-II, Rev-A] stipulates that all MODIS instrument data be processed to Level-1 standard data products and made available within 24 hours after all necessary input data sets are made available. EosDIS requirement 617 [L-II, Rev-A] stipulates that CDOS shall deliver error-corrected Level-0 data to EosDIS within 21 hours of receipt. We interpret these requirements to dictate that Level-1 MODIS data will be made available within 48 hours of the observation.

Based on a literal interpretation of the EosDIS requirements, the delivery of one complete day of Level-1 MODIS data is not required until 72 hours after the beginning of the period. However, as will become apparent, MODIS data processing from Level-1A through Level-3 will be conducted in a series of steps. Given a "scan cube" of sensor data (Table 3), processing will take the data from Level-1A through Level-1B, through Level-2, and will make it available for Level-3 processing independent of the status of neighboring scans. This strategy implements the MODIS/HIRIS Level-1 functional requirement II-C-31 [Ver-1.0, Dec. 1988], which states that the data system "shall allow immediate generation of any products from newly acquired data."

The Level-1 processing for MODIS-N and for MODIS-T will occur independently. Although many of the algorithms employed in the Level-1 processing will be similar or identical for the two instruments, the instruments have fundamental differences in operation, coverage, and user community which dictate that the processing be performed independently. However, given this distinction, we will consider the MODIS Level-1 processing generically, with the understanding that the processing steps must be separately applied to the two instrument data streams.

From Table 4, we see that the MODIS Level-1 processing requirement will encompass a little more than 90,000 scan cubes of data, which must be unpacked and checked, calibrated, Earth located, described, reformatted, and stored. Each scan cube will contain from 0.2 to 1.1 million observations, depending on the instrument and day/night status. Each observation will be either a 12-bit word (Level-1A) or a 16-bit word (Level-1B).

Within each scan cube there are defined a number of scan planes (Figure 2). We have defined one scan plane for each 1 km channel. MODIS-T scans are composed of 32 scan planes, while MODIS-N scans contain 16 planes at night and 60 during the day (4 each for the 500 m bands). Each scan plane contains data at the same wavelength (though not the same detector) for which the similar or identical processing operations will be repeated many times. Corresponding observations in the various scan planes have identical Earth locations (to within 1/10 pixel), except for the four planes for each 500 m band, which are displaced horizontally by a fixed offset of ($\pm$dx, $\pm$dy; dx and dy = 228 m) from a 1 km band center.

2.2 Receive, Unpack, and Check Level-0 Data

As discussed above, the CDHF will receive Level-0 MODIS data from the DHC as a series of data packets. Platform ancillary data, either in the form of data packets or an unpacked data set will also be received by the CDHF from the DHC. The first step of the Level-1 processing at the CDHF will be to convert the data to two-byte integers and form a data cube by reformatting the data.

There are two reasonable ways to form a data cube. The first is to take all of the data from a single scan swath to form a swath cube. This would result in data cubes of 1.67, 0.45, and 2.49 megabytes for MODIS-N during daytime, MODIS-N at night, and for MODIS-T, respectively. The second option is to combine swaths to form a data cube with "equal" (either in number of observations or in area) dimensions along and across track. The former would be approximately 1600 by 1600 for MODIS-N and approximately 1100 by 1100 for MODIS-T. This assumption would generate cubes with volumes of 300, 82, and 77 megabytes.

The Level-1A data will be formed by reformatting the data received from the DHC and appending headers which will contain all of the information needed to describe the data. This will include all of the required instrument engineering data, platform ancillary data, and any other necessary information (obtained from the DHC or other sources).

2.3 Earth Location of the MODIS Observations

The Level-1A processing will include the earth location calculations. This will require the determination of the earth coordinates for some subset of the total data, which we will term "anchor points." This calculation will require the use of a Digital Elevation Model (DEM) to correct for the earth's topography. Two effects due to non-ellipsoidal topography occur: (1) horizontal pixel displacements and (2) illumination and other reflectance changes due to the surface slope. The fraction of pixels to be treated as anchor points and the precise procedure for the application of the DEM has not been fully determined at this time. The Level-1A processing will also require the calculation of the observing geometry. For each anchor point, the satellite and solar elevation and azimuth angles will be calculated. The earth location and geometry data will be appended to the MODIS instrument data.

2.4 Calibration of the MODIS Observations

The Level-1B data will be generated by applying the calibration coefficients to the Level-1A data. The calibration coefficients will be calculated from information contained in the MODIS data packets (such as space looks), as well as data sets available in the CDHF and provided by the Instrument Characterization Team (ICT). The calibration coefficients will have been placed into the headers and carried along with the data during the Level-1A processing.

2.5 Format and Distribute the MODIS Level-1 Products

The highest reversibly processed data will be sent to the DADS for archiving. This will be the Level-1A data as currently defined. A copy of the Level-1A data cube will be sent off to the archive as soon as the processing necessary to form a complete granule of data has been completed. A granule will be the smallest block of MODIS data to be described by Metadata and browse data. This will be the basic unit of data storage in the DADS, though it may not be the smallest block of data that can be recovered from the archive (a MODIS granule might be a scene cube, while a user may be able to order scene planes--individual spectral bands--from one or more scene cubes).

Any irreversibly calibrated MODIS data, in Level-1B form, may also be archived. Because the MODIS instruments have not been calibrated, much less designed, at this point, it is not possible to state whether the calibration process will be reversible; it is possible that only one Level-1 MODIS data product will be sent to long-term archive.

[What do we know about the calibration equations for MODIS-N and -T?]

Metadata will be generated at the CDHF for all core product data (and all other data generated at the CDHF) sent to the archive. The required Metadata has not been completely defined. Metadata will be derived from the MODIS data for every granule of information. The metadata will provide basic information describing the granule's spatial, temporal, and angular coverage. The metadata will also provide information regarding the sensor data, such as a concise but complete pedigree indicating all algorithms and data sets used in the data's creation and their version, the data quality, and the fractional cloud cover. Finally, the metadata will contain ephemeris, the illumination and viewing geometry at key points within the data granule, and other relevant instrument, platform, and Eos ancillary data.

Consider an image divided into four quadrants. At each of the nine corners, metadata could provide the local time, the latitude and longitude, the satellite and solar zenith angles, the relative azimuth, and the true azimuth from north.

The platform and Eos ancillary data could indicate the operating status of each of the Eos facility and PI instruments. NOAA and International Partner instrument status could also be made available.

The metadata volume for a hypothetical example would be:

Descriptive information:	80 bytes
Data processing pedigree:	160 bytes
Location and geometry:	126 bytes
Relevant ancillary data:	80 bytes
Sensor data description:	80 bytes
Total	520 bytes/granule

3. LEVEL-2 PROCESSING

The first step in the Level-2 processing will be to produce masks or data flags which can be used to control the subsequent processing. As an example, cloud flags may be set so that the processing of the individual products would not require a check for cloud cover. A value of each mask parameter would be set for each earth location (Figure 3).

[The efficient "bundling" of multiple algorithms from three disciplines and 24 science team members, each developed to a large extent independently and with its own processing and screeing "quirks" will require some creative design and a significant amount of effort.]

The number of masks to be determined and the number of values for each mask is not yet defined. We anticipate that the first mask to be calculated would be a land cover. A geographic data base would be used to categorize the surface coverage in the pixel. A possible set of surface types might be Open Ocean, Coastal Region, Desert, Mountains, Vegetation Cover, Ice Cover Possible, Ice Cover Certain, etc. It may be efficient to calculate the surface mask as part of the earth location processing at Level-1.

Cloud masks may be generated as the next stage of processing. A set of multiple valued parameter flags would be calculated by various types of analysis of the data. The mask would have a range of values that would be used to control subsequent processing. The flags might be based on cloud type (e.g., Completely Clear, Thin Cirrus, Low Stratus, Broken Cloud, Complete Overcast). Alternatively, the flags might be based on algorithm type (spatial coherence, IR/VIS threshold, Maximum Liklihood Estimation, etc.). The proper number of cloud flag values, and how the values will be calculated, must be determined by the science team. There will be additional masks defined as we determine how the data is to be selected for analysis in the Level-2 core product algorithms (currently under study.

The complete set of masks will be used to control and guide the subsequent processing. As an example, an aerosol property algorithm may only be valid for observations of desert regions with no cirrus present. The appropriate data would be selected by reading the mask values and, only the appropriate data would be processed. The storage of the masks need not consume a large data volume since several mask values could be packed into a single 16-bit word.

It is anticipated that the masks will form the first layers of the Level-2 data cube. This cube will have the same spatial coverage as the Level-1 cube. It may be efficient to store the Level-2 data by simply adding layers to the Level-1 cube. For example, the earth location and earth/sun/satellite geometry data apply to either Level-1 or Level-2 data. Furthermore, users may wish to access combinations of Level-1 and Level-2 data (e.g., radiances at the TOA and ocean-leaving radiances).

The cloud mask would be used to select the appropriate data for processing in the cloud algorithms. It is likely that there will be multiple cloud algorithms depending on the type and thickness of the cloud cover. The cloud mask can be used to control which data is processed in which algorithms. The cloud data products will be generated and several layers will be added to the data cube. The cloud data products will not, in general, be used to calculate other Level-2 data products.

Aerosol parameters will be calculated for those pixels with a small enough amount of cloud cover. The data will be selected by picking those pixels with a cloud mask value less than some limit. Aerosol parameter determination requires a knowledge of the surface characteristics. Different algorithms will be used over different surfaces, i.e. land and ocean. The surface mask will be used to control which algorithms are used on which pixels. We have currently defined algorithms to be used over the ocean, dark green vegetation, and deserts. The aerosol data products will be generated and added to the Level-2 data cube.

The land and ocean disciplines have both expressed a willingness to generate their products starting from surface leaving radiances. Calculation of surface leaving radiance requires that the Level-1 data be atmospherically corrected. Once clouds have been eliminated, and ignoring surface reflectance corrections (such as sunglint and foam on the oceans), there will be several significant factors in the atmospheric data correction: Rayleigh scattering, absorption by ozone, water vapor, and other gases, and aerosol scattering.

The Rayleigh scattering correction will be calculated based on surface pressure data, which will probably be obtained from NMC. The absorption correction will be calculated based on atmospheric profiles or total column depths of ozone, water vapor, and other gases. The data sources for the these profiles and column integrals are not fully identified at this time. The aerosol corrections will be calculated from the aerosol parameters derived from the MODIS data (i.e., there will be sufficient information in the MODIS data for aerosol correction).

One technique that can be used for atmospheric correction is to use a look-up table. This table (or tables) would contain total or partial atmospheric corrections. The atmospheric correction would simply consist of looking up the correction parameters, given the calling arguments and applying them to the data.

[Discussion only...The look-up table would be updated constantly as new observation become available. If surface weather data was obtained every 12 hours, the Rayleigh correction portion of the table would be updated every twelve hours. The ozone corrections would be updated as new ozone observations were made. Similarly, the aerosol observations from the MODIS instruments would be used to update the tabulated values for aerosol correction.]

[Discussion only...There is an advantage to this scheme. The correction table will be sitting there and the corrections will be available. The calculation of surface leaving radiances will not depend on the availability of surface weather data or the success of the aerosol parameters determination. If recent data is not available, the correction will be of lower quality. However, the calculation of the surface leaving radiance can still be done. It is also possible than more accurate corrections can be made by updating the correction table than by using the latest observations. Another consequence of this scheme is that MODIS-N aerosol observations would be used to atmospherically correct MODIS-T data.]

MODIS-T CHANNEL PARAMETERS

Band	Center Wavelength (nm)	IFOV (m)	Center Wavelength (micron)
1	410	1000	0.410
2	425	1000	0.425
3	440	1000	0.440
4	455	1000	0.455
5	470	1000	0.470
6	485	1000	0.485
7	500	1000	0.500
8	515	1000	0.515
9	530	1000	0.530
10	545	1000	0.545
11	560	1000	0.560
12	575	1000	0.575
13	590	1000	0.590
14	605	1000	0.605
15	620	1000	0.620
16	635	1000	0.635
17	650	1000	0.650
18	665	1000	0.665
19	680	1000	0.680
20	695	1000	0.695
21	710	1000	0.710
22	725	1000	0.725
23	740	1000	0.740
24	755	1000	0.755
25	770	1000	0.770
26	785	1000	0.785
27	800	1000	0.800
28	815	1000	0.815
29	830	1000	0.830
30	845	1000	0.845
31	860	1000	0.860
32	875	1000	0.875

MODIS-N CHANNEL PARAMETERS

Band	Center Wavelength (nm)	IFOV (m)	Center Wavelength (micron)
1	470	428	0.470
2	555	428	0.555
3	665	428	0.665
4	880	428	0.880
5	1240	428	1.240
6	1640	428	1.640
7	2060	428	2.060
8	2130	428	2.130
9	413	856	0.413
10	443	856	0.443
11	490	856	0.490
12	520	856	0.520
13	565	856	0.565
14	653	856	0.653
15	681	856	0.681
16	750	856	0.750
17	865	856	0.865
18	908	856	0.908
19	936	856	0.936
20	950	856	0.950
21	3750	856	3.750
22	3959	856	3.959
23	4050	856	4.050
24	4465	856	4.465
25	4515	856	4.515
26	4565	856	4.565
27	6715	856	6.715
28	7325	856	7.325
29	8550	856	8.550
30	9730	856	9.730
31	11030	856	11.030
32	12020	856	12.020
33	13335	856	13.335
34	13635	856	13.635
35	13935	856	13.935
36	14235	856	14.235

Table 1. The center wavelength and IFOV for each of the 36 MODIS-N and 32 MODIS-T bands.

		Contingency 10%	Total
Earth Radius (km)	6371		
Satellite Altitude (km)	705		
Orbital Period (min)	98.9		
MODIS-N # 856 m REF channels	12		
MODIS-N # 428 m REF channels	8		
MODIS-N # 214 m REF channels	0		
MODIS-N # 856 m TIR channels	16		
MODIS-T # 1 km REF channels	32		
MODIS-N # bits/REF channel	12		
MODIS-N # bits/TIR channel	12		
MODIS-T # bits/REF channel	12		
MODIS-N REF Duty Cycle	50%		
MODIS-N TIR Duty Cycle	100%		
MODIS-T REF Duty Cycle	50%		
MODIS-N # Along-track IFOVs	8		
MODIS-T # Along-track IFOVs	32		
MODIS-N # Along-track detectors	480		
MODIS-T # Along-track detectors	32		
MODIS-N Maximum scan angle (deg)	55		
MODIS-T Maximum scan angle (deg)	45		
MODIS-N IFOV FWHM (deg)	6.95E-02		
MODIS-T IFOV FWHM (deg)	8.13E-02		
MODIS-N # pixels along-scan/on-Earth	1582		
MODIS-T # pixels along-scan/on-Earth	1107		
MODIS-N Scan Period (sec)	1.02		
MODIS-T Scan Period (sec)	4.75		
MODIS-N VIS Data (megabits/scan)	6.7	0.7	7.4
MODIS-N TIR Data (megabits/scan)	2.4	0.2	2.6
MODIS-N Daytime Data (megabits/scan)	9.1	0.9	10.0
MODIS-T Daytime Data (megabits/scan)	13.6	1.4	15.0
MODIS-N # Scans/Orbit	5841		
MODIS-T # Scans/Orbit	625		
MODIS-N Daytime Data Rate (mbps)	9.0	0.9	9.9
MODIS-N Nighttime Data Rate (mbps)	2.4	0.2	2.6
MODIS-T Daytime Data Rate (mbps)	2.9	0.3	3.2
MODIS-N Orbital Ave Data Rate (mbps)	5.7	0.6	6.2
MODIS-T Orbital Ave Data Rate (mbps)	1.4	0.1	1.6
MODIS-N Daily Data Volume (gigabits)	490.8	49.1	539.8
MODIS-T Daily Data Volume (gigabits)	123.8	12.4	136.2
Total MODIS Data Volume (gigabits)	614.6	61.5	676.0

Table 2. MODIS-N and MODIS-T data rate and volume estimates.

INSTRUMENT	Along-Track Detectors	Across-Track Scan Positions	Number of Observations	Number of Spectral Bands
MODIS-T	32	1,107	35,424	32
MODIS-N (day; 1 km)	8	1,582	12,656	28
MODIS-N (day; 500 m)[2]	8 X 4	1,582	12,656 X 4	8
MODIS-N (night)	8	1,582	12,656	16

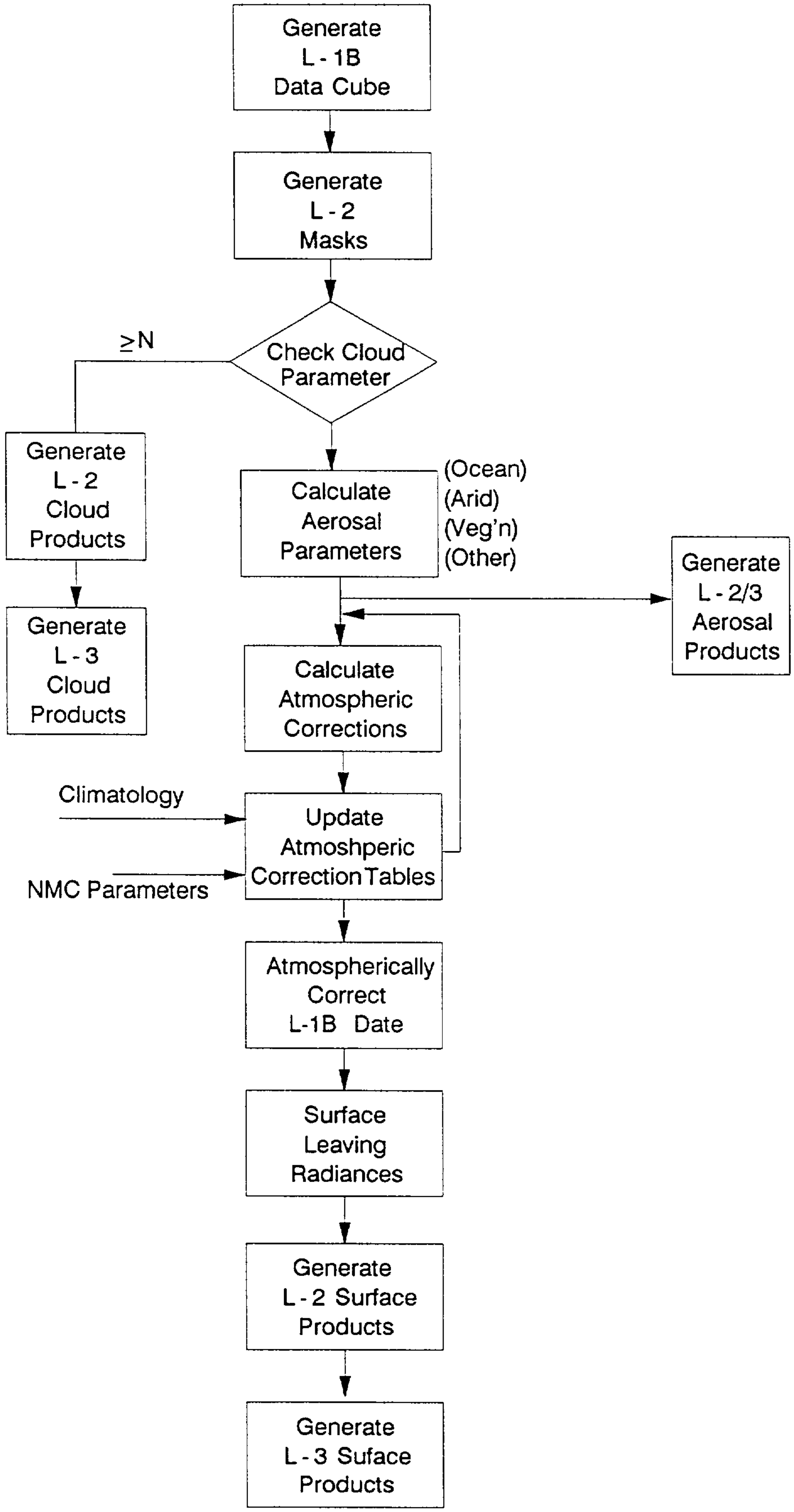
Table 3. The dimensions of MODIS Level-1A data cubes, which consist of a stacked series of planes (one plane for each 1 km channel, four planes for each 500 m channel). The area of each plane is equivalent to the number of scan positions times the number of detectors.

[2]Given the proprietary nature of the MODIS-N designs, the partitioning of the four 500 m detectors between detectors and scan positions is arbitrary.

	BASIC	CALIBRATION 8%	OTHER 2%	CONTINGENCY 10%	TOTAL
MODIS-N # Daytime Scans/day	42,526				
MODIS-N # Nightime Scans/day	42,526				
MODIS-T # Scans/day	6,465				
MODIS-N Day Data # Scan Planes	60				
MODIS-N Night Data # Scan Planes	16				
MODIS-T Daytime Data # Scan Planes	32				
MODIS-N Day Data (obs/scan plane)	12,656	1,012			
MODIS-N Night Data (obs/scan plane)	12,656	1,012			
MODIS-T Daytime Data (obs/plane)	35,424	2,834			
MODIS-N Day Data (obs/scan cube)	759,360	60,749			
MODIS-N Night Data (obs/scan cube)	202,496	16,200			
MODIS-T Day Data (obs/scan cube)	1,133,568	90,685			
MODIS-N Day Data (ANC/scan plane)			253	1,265	13,921
MODIS-N Night Data (ANC/scan plane)			253	1,265	13,921
MODIS-T Daytime Data (ANC/plane)			708	3,542	38,966
MODIS-N Day Data (ANC/scan cube)			15,187	75,936	835,296
MODIS-N Night Data (ANC/scan cube)			4,050	20,250	222,746
MODIS-T Daytime Data (ANC/scan)			22,671	113,356	1,246,924
MODIS-N Daytime Data (megabits/scan)	9.11	0.73	0.18	0.91	10.02
MODIS-N Night Data (megabits/scan)	2.43	0.19	0.05	0.24	2.67
MODIS-T Daytime Data (megabits/scan)	13.60	1.09	0.27	1.36	14.96

Table 4. Parameters describing the number of scans and the data amount within each scan, scan plane (equivalent to the set of observations taken by one 500 m band in one scan), and scan cube (all scan planes within one MODIS-N ar MODIS-T scan).

Processing Scenario

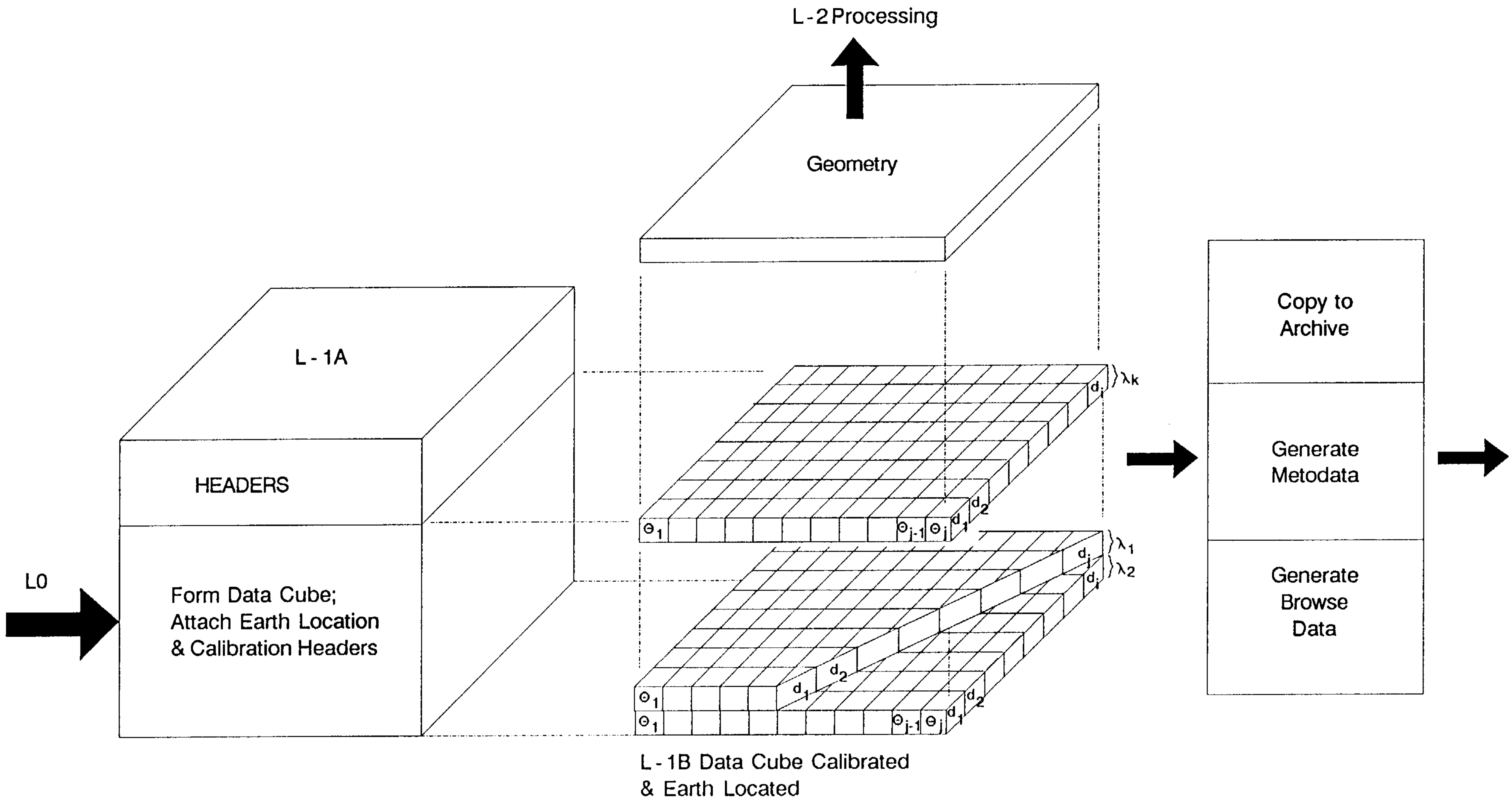


Data Structure

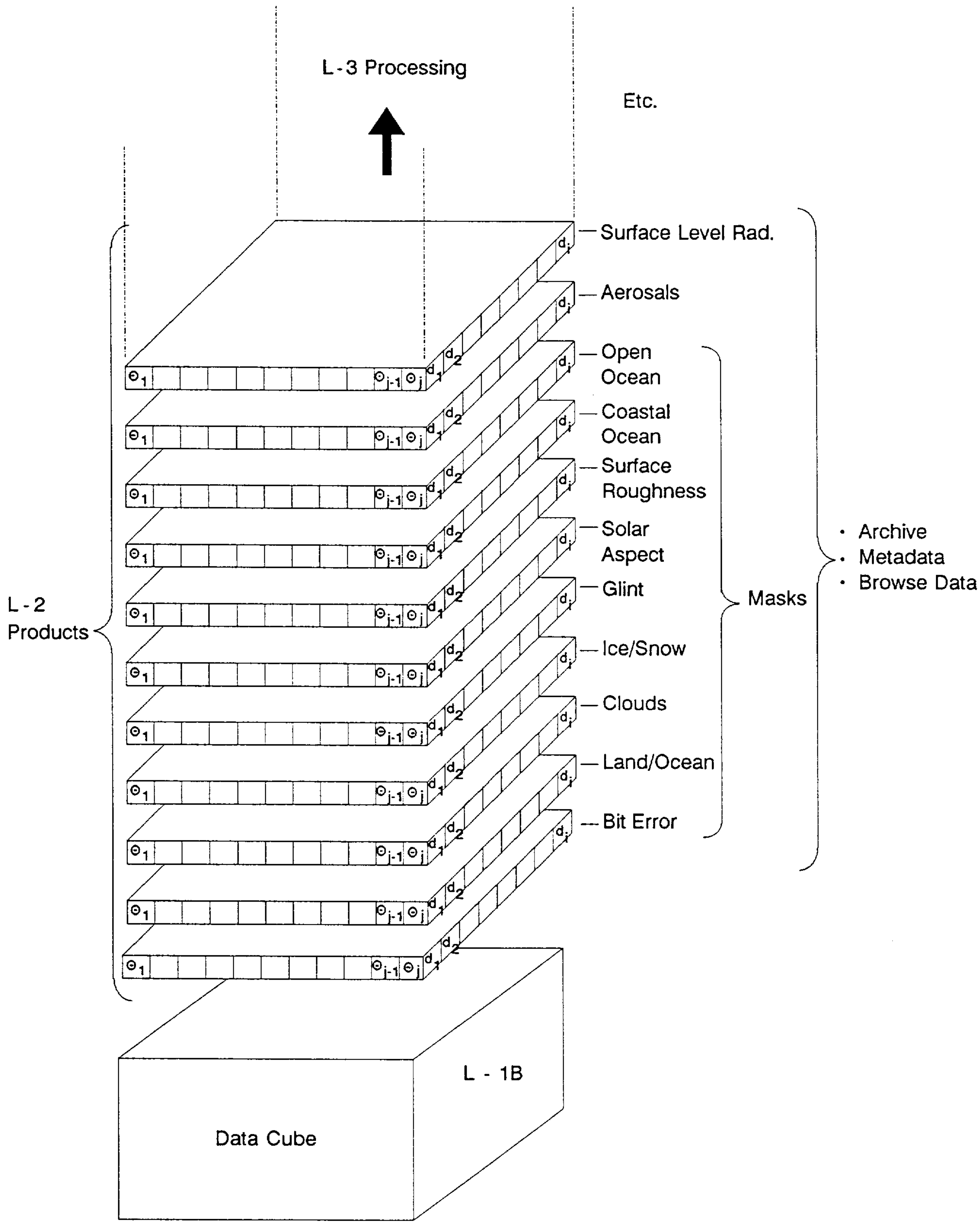
i - along-track FOV's

j - cross-track FOV'S

k - spectral channels high



Level - 1 Processing



Level - 2 Processing